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Potential for Energy Cost Reductions in "Hamilton Class" Cutters Through Fuel Modification

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G. Plank *
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Cambridge MA 02142

September 1981
Final Report

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16. Abstract

A review of all pertinent and available literature on the use of blended fuel and water-in-fuel emulsions in marine power plants was accomplished with special attention paid to the use of this technique with gas turbines. Telephone contact was made with the engineering officers on all of the available (in-port) "Hamilton Class" cutters and "Polar Class" icebreakers to determine the operating schedules of the gas turbines on these vessels as well as fuel consumption and maintenance history. The opinions of the engineering officers were solicited with respect to any special problems which may exist, either with the hardware or operations of the vessels that would act to prevent or impede the use of a water-in-fuel emulsion. A cost/benefit analysis was performed for the case of a blended fuel for the diesels and a water-in-blended fuel emulsion for the gas turbines. Conclusions are drawn on the feasibility of implementing these techniques on a 378-foot "Hamilton Class" cutter summarizing the problems which would have to be overcome and the probability for success of such a project.

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PREFACE

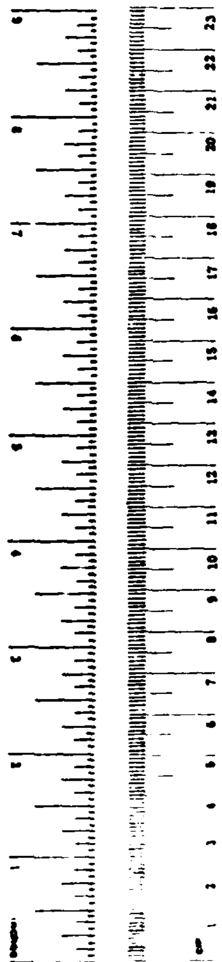
The Research and Special Programs Administration's Transportation Systems Center and the U.S. Coast Guard's Office of Research and Development, both of the U.S. Department of Transportation, examined the work performed to date on the use of blended fuels and water-in-fuel emulsions in diesels and gas turbines. On the basis of this examination, the feasibility of utilizing these techniques of fuel modification with the diesels and gas turbines installed in the twelve (12) "Hamilton Class" Coast Guard cutters currently in service was assessed. The use of blended fuel in the diesels and emulsified blended fuels in the gas turbines is feasible, only the particular blend needs be determined. Considerable fuel cost savings can be realized.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

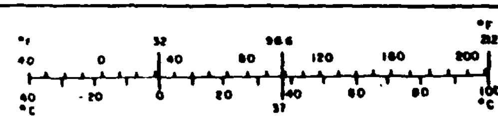
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 BACKGROUND

The ever increasing cost of crude oil and its derivatives, has created a growing interest in the Coast Guard to improve the fuel economy of their in-service marine power plants. An effort is continuing to determine what changes, if any, in existing hardware, fuel specifications, or operations can effect a significant improvement in fuel economy or cost, as well as pollution control, in the day to day operations of their cutters.

An examination of ways in which to improve the performance of the main propulsion engines (FM 38TD8-1/8 diesel engine) of the 378-foot "Hamilton Class" High Endurance Cutter (WHEC) has been carried out for the Transportation Systems Center by Colt Industries.[1] This study has shown that significant improvement in engine performance can be made if conversion from the existing turbo-charger scavenging-air system to a series type system is implemented. Beyond performance improvement, other work has shown that similar engines can be modified to run on heavier cheaper fuel than the distillate normally used.

In addition, each of the twelve (12) "Hamilton Class" cutters is equipped with two (2) Pratt and Whitney FT-4 marine gas turbine engines. These same engines are also used on the Coast Guard "Polar Class" icebreakers. Recent experience by Seatrain Lines has shown that these engines can be run on a water-in-blended fuel emulsion with considerable reduction in fuel costs.

It is desired therefore, to determine what cost reductions, if any, can be achieved in Coast Guard operations using heavy fuel, either in a blend or water-in-fuel emulsion.

As the "Polar Class" icebreakers (two are in service) have not yet established a predictable use profile, the analysis developed in this report is restricted to the power plants on board the "Hamilton Class" cutters.

1.2 OBJECTIVE

The objective of the present effort is to examine the work performed to date on the use of blended fuels and water-in-fuel emulsions in diesels and gas turbine engines and determine, on the basis of this examination, the feasibility of utilizing these techniques with the diesels and gas turbines installed in the twelve (12) "Hamilton Class" Coast Guard cutters currently in service.

1.3 APPROACH

A review of all pertinent and available literature on the use of blended fuel and water-in-fuel emulsions in marine power plants was accomplished with special attention paid to the use of this technique with gas turbines. Telephone contact was made with the engineering officers on all of the available (in-port) "Hamilton Class" cutters and "Polar Class" icebreakers to determine the operating schedules of the gas turbines on these vessels as well as fuel consumption and maintenance history. Diesel operating schedules and fuel consumption history is readily available in Coast Guard documentation. The opinions of the engineering officers were solicited with respect to any special problems which may exist, either with the hardware or operations of the vessels that would act to prevent or impede the use of a water-in-fuel emulsion. A cost/benefit analysis is performed for the case of a blended fuel for the diesels and a water-in-blended fuel emulsion for the gas turbines. Conclusions are drawn on the feasibility of implementing these techniques on a 378-foot "Hamilton Class" cutter summarizing the problems which would have to be overcome and the probability for success of such a project.

2. OPTIONS FOR FUEL MODIFICATION

Efforts to date have identified three (3) principal techniques for fuel modification that show potential for reductions in fuel consumption and/or operational costs. These techniques are (1) blended fuels for use in diesels (2) distillate fuel emulsions for use in diesels or gas turbines and, (3) blended fuel emulsions for use in diesels or gas turbines.

2.1 BLENDED FUELS

The use of blended fuels (a mix of distillate and heavy fuels) in large diesel engines designed for these fuels is current commercial practice. Successful operation of a large diesel engine has been demonstrated with heavier fuels up to a viscosity of 3500 seconds Redwood No. 1 (sec R1).[2] The potential for use of blended fuels with the main propulsion diesels (Fairbanks-Morse 38TD8-1/8) of the "Hamilton Class" cutters has not yet been established but engines of comparable speed have been said to tolerate fuel viscosities of up to 1000 sec R1.[3]

Table 1 summarizes the viscosity tolerance of a number of large medium speed diesels. The viscosities resulting from various blends of DF2 (45 secR1) and FS6 (3500 sec R1) are shown in Table 2. The cost/benefit analysis developed in this report (Section 4) for the "Hamilton Class" diesels presumes the technical feasibility of using blended fuel in these engines.

The use of blended fuels in a gas turbine without further modification appears unfeasible because of the short burn time required to retain the flame within the burner can.

2.2 DISTILLATE FUEL EMULSIONS

The second option for fuel modification to reduce fuel consumption and/or costs is the use of a water-in-fuel emulsion of a distillate fuel. This type of emulsion has the potential for use with both diesel engines and gas turbines. Cost reduction

TABLE 1 - FUEL TOLERANCE OF MEDIUM -SPEED DIESELS

ENGINE	MODEL	RPM	VISCOSITY TOLERANCE (sR1)*
MAK	M601	425	3500
PIELSTICK	PC2-5	520	850
MAN	40/45	600	2500
B&W	s/u28	775	200
>EMD	567	835	500
***F-M	38TD8-1/8	900	?
SULZER/MAN	AS 25/30	1000	1000
MAN	20/27	1000	400
**ALCO	251	1000	400
RUSTON	RKC	1000	1500
PIELSTICK	PA6	1000	3500
ALCO	270	1000	1500

*By Design or test, not necessarily a maximum

**Main propulsion - 210' WMEC; endurance tested at 400 sR1

>Auxiliary engine - 378' WHEC; fuel system limited to 700 sR1

***Main propulsion - 378' WHEC

TABLE 2 - VISCOSITY VARIATION IN BLENDED FUELS

USING:

FUEL	VISCOSITY (sR1)	PRICES ($/GAL)
DF2	45	1.22
FS6	3500	0.87

FUEL (%)			
DF2	FS6	BLEND VISCOSITY	PRICE DIFFERENTIAL ($/GAL)
50	50	180	0.18
40	60	280	0.21
30	70	470	0.25
25	75	650	0.26
20	80	890	0.28
10	90	1700	0.32

using this technique depends upon a significant reduction in specific fuel consumption (SFC). Experience has shown, as documented in the following paragraphs, that significant improvements in SFC do not occur in diesels or gas turbines and that the primary thrust of emulsified distillate fuel research for gas turbines has been in the interest of smoke reduction. Therefore, no specific analysis for the potential of distillate fuel emulsions is presented in this report.

2.2.1 Previous Studies with Diesels

Work has been performed for the Coast Guard and TSC aimed at extending the effectiveness of fuels being used in marine diesel power plants through the use of water-in-fuel emulsions. The initial work,[4] carried out by Southwest Research Institute (SwRI) on a single cylinder diesel using unstabilized water-in-fuel emulsions showed that decreases in fuel consumption of up to 5.1% could be obtained and that decreases in oxides of nitrogen of up to 60% and Bosch smoke numbers of up to almost 70% could be attained. Unburned hydrocarbons, however, were found to increase by as much as 130% while the effect on carbon monoxide was indeterminant with measured increases of as much as 170% and decreases as much as 52% depending on engine speed and power and water content of the fuel. No problems were encountered in engine operation at any test condition.

Further work[5] at SwRI using unstabilized emulsions in multi-cylinder engines has indicated that an average fuel saving of about 2.5 percent could be obtained with a Cummins VTA-1710 engine (four-stroke) at the most frequently encountered operating conditions and water concentrations of 15-25 percent. Significant reductions in exhaust smoke were also observed. However, no statistically significant reduction in fuel consumption could be seen when using a Detroit Diesel 12V-149TI engine (two-stroke) under similar conditions. Gaseous exhaust emissions tended to increase with the presence of water in the fuel with both engines. Particulate emissions increased only slightly with water in the Detroit Diesel engine. No adverse effects were noted in the hardware of either engine with the use of

emulsions. In a similar study,[6] Murayama et al., using water-in-fuel emulsions stabilized with a surfactant, also found a large reduction in NO_x concentration as well as improvements in fuel economy and exhaust smoke reduction. In a very early study done by Cornet and Nero[7] on a small diesel engine, they found no improvement in specific fuel consumption using water-in-fuel emulsions but did suggest that exhaust smoke was reduced as well as carbon deposits in the engine.

The basis for improvements in specific fuel consumption with the use of water-in-fuel emulsions is the presence of "microexplosions"[8-12] in the combustion of the emulsions. After injection into the combustion chamber, a water-in-fuel droplet becomes superheated causing the water to vaporize violently, shattering the droplet, resulting in much finer atomization of the fuel and more thorough mixing of fuel and air. This phenomenon is shown conceptually in Figure 1 and is photographically documented in Figure 2. The reduction in exhaust NO_x and smoke are believed to be due to the reduction in temperature in the combustion region as well as improved mixing due to the "microexplosions".

2.2.2 SwRI Efforts for the Navy - Gas Turbines

The Navy's principal interest in the use of emulsified fuels with gas turbines has been for the purpose of reducing exhaust smoke. Much of the work to this end has been performed at the Southwest Research Institute by C. A. Moses and his associates.[13] Their test apparatus consisted of a combustor rig made from Allison T-63 engine hardware. Using JP-5 Navy jet fuel, they recorded a continuous decrease in exhaust smoke as the amount of water in the emulsion was increased up to 50%. A maximum reduction of 80% in exhaust particulate concentration was observed. The greatest smoke reduction was always observed at the highest power points of the T-63. NO_x was reduced up to 50% with increased water content at the highest power levels. The concentration of CO and unburned hydrocarbons increased with increased water

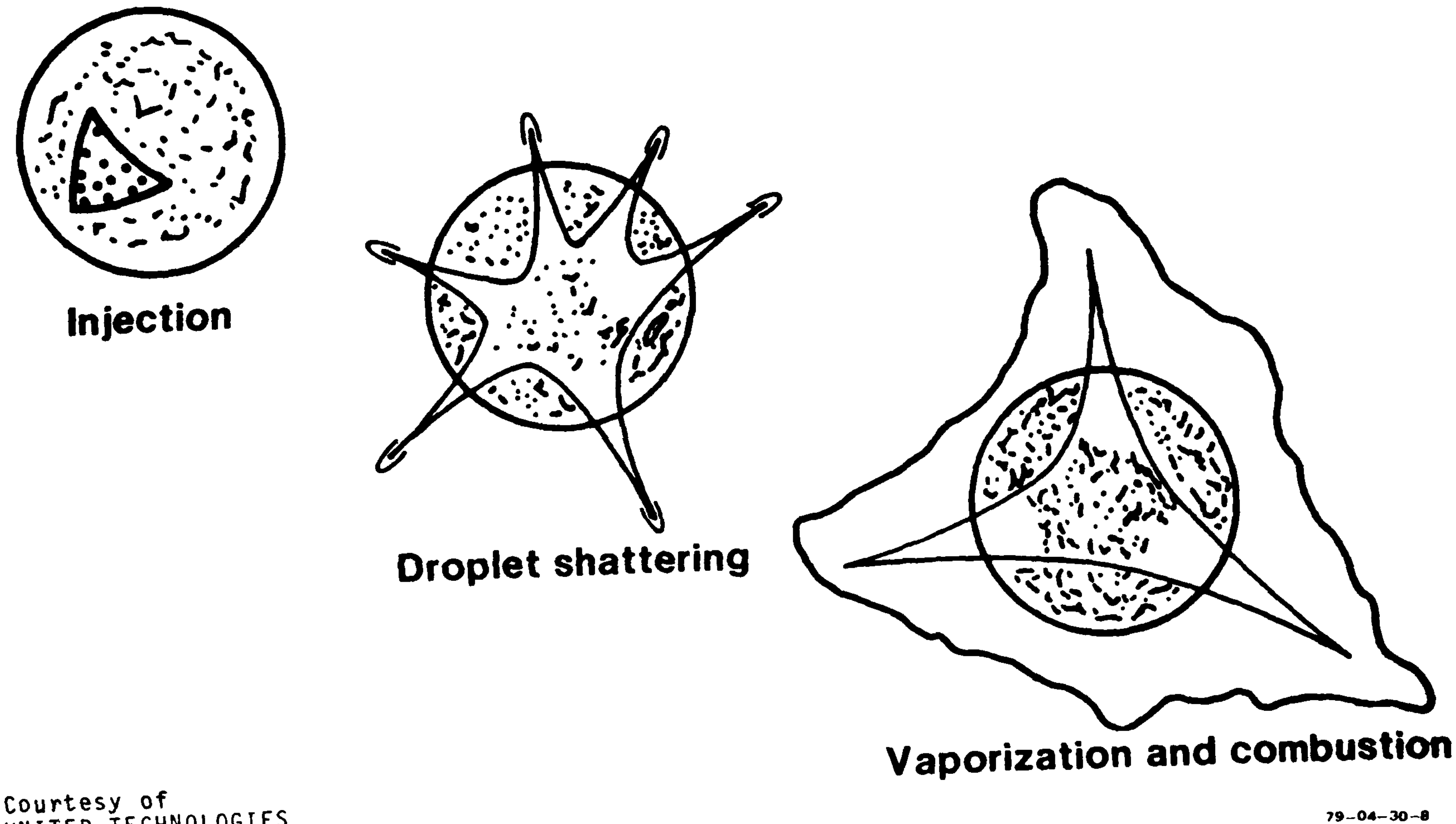

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FIGURE 1. COMBUSTION OF WATER EMULSION DROPLET

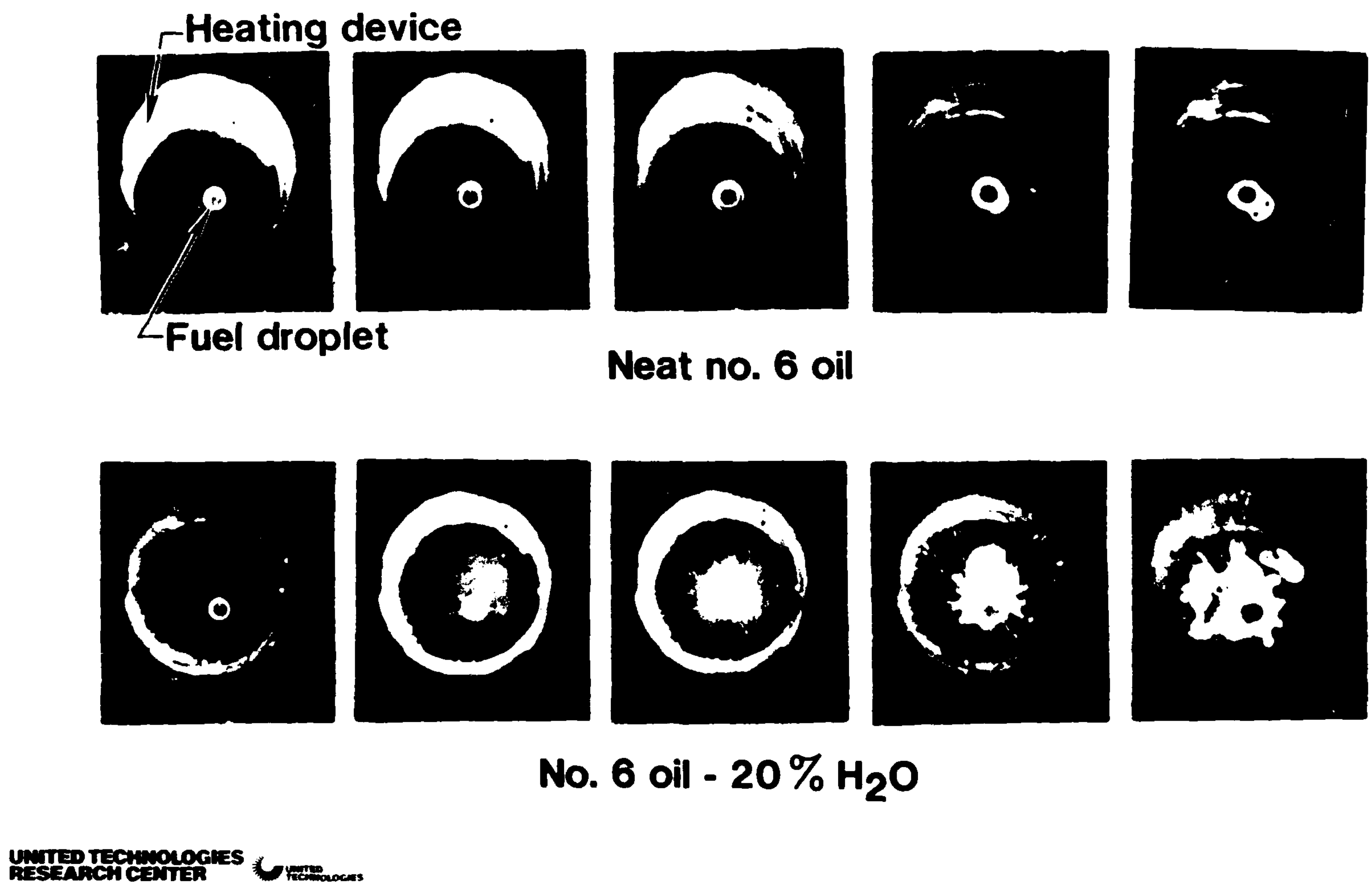

FIGURE 2. COMBUSTION OF A NO. 6 OIL DROPLET

content; maximum levels occurring at the lower power conditions. Combustion efficiency, as calculated from exhaust chemistry, always decreased with the addition of water.

To verify the data gathered at SwRI on the combustion rig, and to gather other data on engine performance, further work was performed at the Naval Air Propulsion Center in Trenton, N.J. to evaluate the concept using full scale systems.[14] This work was performed to examine the effects of the emulsion on fuel control components and performance, full scale engine components and performance, and test cell exhaust smoke and engine exhaust emission levels. The results indicated that while water-in-fuel emulsions could be used effectively to reduce gas turbine engine exhaust smoke to acceptable levels (20 percent visual opacity - Ringlemann 1 standard), there were certain problems attached to its use that may render the technique impractical. With the particular engine under test (J79-GE-10) the fuel control system did not have the flow capacity to deliver the required volume of both fuel and water at the higher power conditions. In addition, the engine acceleration time requirement is exceeded when operating with sufficient water to reduce the test cell smoke to 20 percent opacity. Slight corrosion was also observed in the fuel control system after a two month storage period. They recommend that further work be done to determine the acceptability of adjusting the fuel control specific gravity setting to accommodate the additional fluid flow required to operate at the higher power levels with the addition of water to the fuel.

2.2.3 Pratt and Whitney Studies - Gas Turbines

Most of the work on water-in-fuel emulsions being conducted at Pratt and Whitney Aircraft has been performed by Dr. L.J. Spadaccini and his associates[10] at the United Technologies Research Center in East Hartford, Connecticut. They have performed tests on gas turbine combustors using water-in-oil emulsions with No. 2 and No. 6 oil as the continuous phase. One of the characteristics noted when using No. 6 fuel oil was an increase in viscosity with increased water concentration. No such increase was noted with

No. 2 fuel oil. They suggest a slightly higher than normal preheat for the No. 6 oil to obtain an equivalent viscosity. The emulsions made with No. 2 oil were found to be unstable and a surfactant was added as a stabilizer.

These investigators are responsible for the high speed photographs shown in Figure 2 of single droplets of water/No. 6 oil emulsions, demonstrating the phenomenon of "microexplosions". The photographs clearly show the droplets shattering as they are heated. The finer atomization resulting from these microexplosions results in more complete combustion of the fuel and a shorter combustion time required to consume the dispersion fuel droplet than was required to burn neat fuel.

To further examine the combustion characteristics of the water-in-fuel emulsions, they conducted several tests on an actual gas turbine combustor. To simulate the operating conditions of an FT4 combustor, they used an FT12 burner can modified to operate with the air and fuel conditions of an FT4 combustor. Redwood 650 oil and four-emulsions of it were tested, using 4, 5, 7.5 and 10 percent water. They found that combustion efficiency was always increased with the addition of water and was maximized with approximately 5% water (15% increase in efficiency). Smoke emissions were also found to decrease in every case with maximum smoke reduction (16% reduction in SAE smoke number) occurring with 4% water added. The temperature distribution at the combustor exit was acceptably uniform (pattern factor was always less than 0.2). They also found that NO_x emissions increased initially to a maximum with 4% water and decreased with further addition of water. Carbon monoxide and unburned hydrocarbons decreased to a minimum with 4% water and increased with further addition of water. They concluded that emulsified fuel could improve the efficiency of a gas turbine combustor without adversely affecting the turbine inlet temperature profile or the pollutant emissions rate. They recommend that further studies be conducted to determine to what extent water-in-fuel emulsions can broaden the range of fuels compatible with

current combustion devices and that further consideration be given to combustor design, system modification, and assessment of operational costs with the use of emulsified fuels.

2.3 BLENDED FUEL EMULSIONS

The third, and most promising option for fuel modification to reduce costs is the use of a water-in-fuel emulsion utilizing a blended fuel. The principal advantage of this technique rests not so much in a resulting conservation of fuel, but in the ability to burn a heavier, less expensive fuel. This advantage is primarily applicable to gas turbines. Therefore, the cost/benefit analysis developed in this report (Section 3) for the use of blended fuel emulsions in gas turbines is restricted to a consideration of the differential in cost between distillate and blended fuels; no impact of an improvement in SFC is assumed or implied.

Since the cost/benefit analysis is driven by the fuel cost differential and less dependent upon improvements in SFC that may result from emulsification, no further presentation of results for diesels beyond that of paragraph 2.1 and Section 4 for blended fuels is necessary. The impact on the cost/benefit analysis resulting from a consideration of improvements in SFC due to emulsification was studied and was found to be sufficient to recommend that emulsification should be assessed in any blended fuels program conducted for a medium speed diesel.

2.3.1 General Electric Studies - Gas Turbines

General Electric has investigated the use of water-in-fuel emulsions in the marine conversion of their LM2500 gas turbine engine.[15] The fuel utilized in this work was Redwood 1500 which is about 85% Bunker C. They initially used a simple sonic on-line homogenizer to create the emulsion, but this did not produce the degree of atomization necessary for complete combustion within the confines of the combustor can. To further pursue the investigation, they rented a Gaulin homogenizer (the type used by Seatrain Lines) but this too led to unsatisfactory combustion. A final attempt to produce the fine atomization required to adequately

burn this heavy fuel was made using a high pressure atomization technique (no emulsion). This proved to be much more successful than the water-in-fuel emulsion technique.

Even with the successful combustion of the Redwood 1500 fuel however, a major problem persisted. The magnesium added to the fuel to inhibit the buildup of vanadium ash in the turbine section produced a magnesium ash that was unusually tenacious and would not simply wash off. This serious problem, as well as the unsuccessful tests with the water-in-fuel emulsion, has led General Electric to seek other approaches to burning heavy fuel.

2.3.2 Seatrain - Seaworthy Studies - Gas Turbines

Seatrain Lines, owners of four gas turbine powered "Euroclass" cargo vessels, together with Seaworthy Engine Systems, are responsible for the most ambitious program to date, using emulsified fuels in gas turbine engines.[16-20] After an extensive analysis of fuel utilization and costs, prompted by the rising price of oil, they retrofitted all four of their "Euroclass" vessels to operate on water-in-fuel emulsions. In addition, they re-designed the propellers to maximize fuel economy. The water-in-fuel emulsion allowed them to use a much lower grade of fuel and they did, in fact, use a blend of fuel composed of 75 percent "Bunker C" (for the first time in any aircraft-derivative gas turbine anywhere). Although Seatrain Lines has since replaced all their gas turbines with low speed diesel engines for purely economic reasons due to unprecedented oil price increases, their experience is of great value to the Coast Guard who, because of the speed and reliability required in their search, rescue and law enforcement efforts, must use the gas turbines currently installed in many of their cutters.

There are a number of problems to be overcome before heavier fuels may be used in gas turbines. A major problem, of course, in utilizing "Bunker C' residual fuel is its relatively high content of sodium and vanadium. The sodium must be removed to prevent the corrosion that occurs in the turbine hot section, sodium sulfication being the major cause of this corrosion. To reduce the chloride

sea-salt content of the fuel to acceptable levels (1ppm) a complete fuel washing system was built and installed in the Seatrain vessels.

The initial step in cleaning the fuel is the addition of a chemical and demulsifier and clean water. These are mixed with the fuel and the resulting mixture is transferred to a settling tank. The constituents are then recirculated for a period of time after which the fuel/water mixture is allowed to settle statically. The wash water, containing dissolved salts from the fuel, then settles out. The excess water is drained from the settling tank and the fuel is further cleaned in a centrifuge. After this cleansing process is complete, the fuel is stored in a day storage tank. When used, the fuel is drawn from the day tank and both vanadium inhibitor and combustion water are added at rates controlled as a function of fuel flow to the engine. The addition of a vanadium inhibitor, which may be either magnesium or magnesium oxide, is required in order to diminish the corrosive effects of vanadium pentoxide on the hot turbine section of the gas turbine. The magnesium will react with the vanadium to produce magnesium vanadate which is a harmless ash that may be removed when the engine is washed. The water/fuel mixture with inhibitor then goes to a homogenizer which creates the emulsion prior to distribution to one or both engines. To monitor the critical levels of sodium and vanadium, they installed an atomic absorption spectrophotometer.

3. POTENTIAL FOR USE OF BLENDED FUEL EMULSIONS IN COAST GUARD GAS TURBINES

3.1 DISTILLATE FUELS VS. HEAVY FUELS

The significant savings in costs experienced by Seatrain Lines was due to their ability to burn lower cost "Bunker C" residual oil. While the "Bunker C" oil has characteristics that result in slower burning, the emulsion and the presence of micro-explosions resulted in a combustion time compatible with the geometry of the combustor of the FT4 gas turbine engine utilized in the "Euroclass" freighters. The combustor can length and configuration was designed to accommodate distillate fuel. Lower grades of fuel have longer burning times and would therefore be incompatible with the burner can design. To shorten burning time the heavier fuel is preheated before it enters the fuel nozzles which results in reduced droplet size. Further reduction in droplet size due to the presence of microexplosions occurring in the emulsion results in complete combustion of the fuel within the length of the combustor can.[17]

An emulsion using a heavier fuel is no more difficult to produce than that using distillate fuel and, in fact, may be easier to produce due to the presence of natural surfactants. The type of fuel does not place significant restrictions on the ability to produce a water-in-fuel emulsion. The significance then, in the use of a water-in-fuel emulsion in a gas turbine, is not the reduction in specific fuel consumption as much as the ability to burn a less expensive residual fuel.

3.2 STABILIZED VS. UNSTABILIZED EMULSIONS

Depending upon the fuel being used, it may or may not need the addition of a surfactant to maintain the stability of the emulsion once it is created. In the case of No. 6 fuel oil, which contains natural surfactants, the resulting water-in-oil emulsion is very stable and may be stored for long periods of time without separation. On the other hand, if extended storage of an emulsion of No. 2 oil and water is desired, a surfactant must be added.

The storage of an emulsion for an extended period of time may present a problem in tank maintenance because of the water content. The water may encourage the growth of microorganisms, increasing the effort required to maintain clean tanks. The current Coast Guard tank maintenance program for the "Hamilton Class" cutters includes the periodic addition of a fungicide (BIOBOR JF) to the fuel to prevent such growth. The storage of a water in oil emulsion would surely aggravate any problems of microorganism growth. Corrosion of tanking and piping may also become a problem with the long term storage of a water-in-oil emulsion.

An alternative is to create the emulsion immediately before delivering the fuel to the combustion chamber, eliminating the need for a surfactant, as the emulsion will remain stable for at least the short period of time between its creation and combustion. It may also be easier to achieve better control of droplet size with an "on line" emulsifier.

The success experienced by Seatrain Lines, Inc. with their water-in-oil emulsion system was achieved with unstabilized fuel. Unless a surfactant aids in extending the fuel or reducing smoke or other pollutants, it appears that the most effective approach is to use unstabilized fuel and create the emulsion immediately before combustion.

3.3 FUEL SYSTEMS AND TANKING

The fuel systems and tanking of the "Hamilton Class" cutters are constructed to handle a single fuel type for both the diesel power plants and the gas turbine engines. A single day tank serves whichever power plant is being used at a particular time. Because the cutter has a fixed fuel capacity, the range of the cutter will be reduced if the emulsion is pre-mixed and stored on board and the specific fuel consumption has not been significantly improved by the use of the water-in-fuel emulsion. This is due to the fact that part of the fuel carrying capacity would then be utilized

by the water in the emulsion. This, along with other reasons already discussed, is another argument for utilizing an "on line" emulsifier to produce the emulsion just prior to combustion.

3.4 WATER SUPPLY, PRODUCTION AND UTILIZATION

The fresh water carrying capacity of all of the 378-foot "Hamilton Class" cutters is 17,000 gallons. The nominal production capacity of the on board still is 10,000 gallons per day with actual realized production of about 7500 gallons per day. All of these cutters have been required to change to fresh water in their sanitary systems which places an extra burden of 500-1000 gallons per day on fresh water usage when underway. Total utilization of the fresh water supply appears to be about 6000-7000 gallons per day when underway. At the rate the gas turbines are currently used, and under any conceivable emergency situation, the fresh water production and storage capacity of these cutters appears to be sufficient to support the use of water-in-fuel emulsions.

3.5 TWO-FUEL SHIP OR COMPLETE HEAVY FUEL CONVERSION

The 378-foot WHEC "Hamilton Class" cutters have, by design, two very distinct propulsion systems; diesel engines for routine propulsion and gas turbines for emergency and high performance propulsion, both operating from a common fuel system. The complete conversion of one of these vessels to a heavier (blended) fuel would mean the simultaneous development of both diesel and gas turbine blended fuel systems which initially at least, would reduce the operational reliability and availability of the cutter. The concept of conversion to a heavier fuel on a single fuel ship is further complicated by the fact that heavier fuels are not available at all commonly used sources of fuel supply. For these reasons the complete conversion to a heavier fuel is impractical. The most cost effective approach to the conversion of the gas turbine to heavy fuel is to perform the necessary R&D with minimal interruption of the service for which the cutter was intended, i.e., continue operation of diesels on distillate fuel during

the conversion. The approach used by Seatrain Lines, Inc. on their "Euroclass" vessels could be used on the Coast Guard Cutters but on much firmer ground because of Seatrain's experience. Redesign of fuel system plumbing would be comparable to that done on the "Euroclass" vessels as these vessels ultimately carried both distillate and heavy fuel oil, using the distillate for in-port maneuvering and a blended fuel at sea. For several reasons then, a two-fuel ship would retain cutter reliability and availability throughout the development process. On the other hand, the majority of engineering officers contacted in this study did not wish to see their cutter converted to two fuels because of the added complexity in fuel system plumbing. If a conversion to two fuels were implemented, additional training for the engine crew and system safeguards against mishandling of fuel would be necessary.

3.6 COSTS AND BENEFITS

The conversion to emulsified fuel in the "Euroclass" vessels was a very profitable endeavor primarily because of the large quantity of fuel that each vessel consumes each year. The utilization of the gas turbine engines in the "Hamilton Class" cutters however, is considerably less, requiring a much closer look at the costs and benefits to determine if such a conversion is warranted.

The March, 1977 costs for the ASIALINER shipboard plant to water wash and emulsify the Redwood 600 fuel was about $150,000.[17] At current (October 1980) prices this would be about $206,716.* Estimates on fuel treatment, including fuel additives, clean water for washing and emulsifying, and fuel heating, amount to about $2.00 per ton of fuel. The estimate for system maintenance was about half that for the second generation system. The benefit of converting a gas turbine engine to burn heavy fuel is the money

*Estimate based upon the Producer Price Index for General Purpose Machinery and Equipment, U.S. Dept. of Labor, Bureau of Labor Statistics.

saved due to the price differential between the blended fuel and the distillate normally used in the gas turbine. Current (October 1980) DOD prices on these items are $1.22 per gallon for #2 diesel fuel and $0.87 per gallon for FS6 (Viscosity = 3500 sec R1), equivalent to "Bunker C". The resulting blend of 75% FS6 and 25% distillate would cost $0.96 per gallon (see Table 2). The price differential (D) between the blend and distillate would be $0.26 per gallon.

Estimates on the utilization of gas turbines in the "Hamilton Class" cutters range up to 200 hours per year per vessel at 75% power. Minimum utilization allowed* is at least twenty (20) hours per quarter per engine in addition to starting them weekly to perform required maintenance procedures. This amounts to 160 hours per year per cutter or a consumption (C) of 160,000 gallons per year per cutter if we assume a fuel consumption rate of 1000 gallons per hour. This estimate for the consumption rate is in line with manufacturer's specifications and estimates by engineering officers on the cutters. A discount rate of 10%** is required for the type of analysis being performed. We are assuming the system is installed in four (4) cutters the first year, four (4) cutters the second year and four (4) cutters the third year. An initial R&D cost of $120,000 is assumed. A summary of the assumptions made for this analysis is given in Table 3. A summary of present value of costs over a period of twenty (20) years is shown in Table 4. A summary of the present value of benefits over a period of twenty (20) years is given in Table 5. In this table we consider the differential inflation rate between the average general inflation rate and that expected to be applicable to the inflation of fuels. As a reasonable range we have chosen zero, five, and ten percent differential inflation. From the previous tables a benefit/cost ratio table has been constructed in Table 6. In the left hand column of this table are three different installation costs. In 1977, the

*Comandant Note 9234, U.S. Coast Guard Telecommunications Center May 23, 1979.

**Office of Management & Budget, Circular No. A-94, Revised, March 27, 1972.

TABLE 3. ASSUMPTIONS FOR COST BENEFIT ANALYSIS (GAS TURBINES)

- DISCOUNT RATE = 10%
- INSTALLATION LIFE = 20 YEARS
- INSTALLATION: 4 CUTTERS YEAR 1
  4 CUTTERS YEAR 2
  4 CUTTERS YEAR 3
- R&D COSTS APPLIED AT YEAR ZERO = $120,000
- ANNUAL FUEL CONSUMPTION BASED ON 1000 GAL/HR
- SYSTEM MAINTENANCE AND OPERATING COSTS:
  FUEL ADDITIVES AND HEATING - $2.00/TON OF FUEL
  MAINTENANCE - $1.00/TON OF FUEL
- DIFFERENTIAL FUEL COSTS = $.26/GAL

TABLE 4. PRESENT VALUE OF COSTS (GAS TURBINES)

YEAR	COST	PVF	PV OF COSTS	PV OF CUMULATIVE COSTS
0	120K	1.0	120K	120K
1	4I	0.954	3.816 I	120K + 3.816 I
2	4 I + .0387 C	0.867	3.468 I + 0.0336 C	+ 7.284 I + 0.0336 C
3	4 I + .0774 C	0.788	3.152 I + 0.0610 C	+ 10.436 I + 0.0946 C
4	.1161C	0.717	.0832 C	+ 0.1778 C
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20		0.156	0.0181 C	0.8288 C

FOR 20 YEARS: COST = $120 K + 10.436 I + 0.8288 C

WHERE: I = INSTALLATION COST

C = FUEL CONSUMPTION/CUTTER/YEAR (GALLONS)

TABLE 5. PRESENT VALUE OF BENEFITS (GAS TURBINES)

		PVF			PV OF BENEFITS			PV OF CUMULATIVE BENEFITS		
		DIR			DIR			DIR		
YEAR	BENEFIT	0	5	10	0	5	10	0	5	10
0	0	1.0	1.0	1.0	0	0	0	0	0	0
1	0	.954	.977	1.0	0	0	0	0	0	0
2	4 CD	.867	.933	1.0	3.468 CD	3.732 CD	4 CD	3.468 CD	3.732 CD	4 CD
3	8 CD	.788	.890	1.0	6.304 CD	7.120 CD	8 CD	9.772 CD	10.852 CD	12 CD
4	12 CD	.717	.850	1.0	8.604 CD	10.200 CD	12 CD	18.376 CD	21.052 CD	24 CD
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20		.156	.404	1.0	1.872 CD	4.848 CD		85.660 CD	133.468 CD	216 CD

FOR 20 YEARS: BENEFIT = 85.66 CD AT 0% DIR
= 133.46 CD AT 5% DIR
= 216 CD AT 10% DIR

WHERE: C = FUEL CONSUMPTION/CUTTER/YEAR (GALLONS)
D = DIFFERENTIAL FUEL COSTS

TABLE 6. BENEFIT/COST RATIOS (GAS TURBINES)

C/CUTTER/YEAR

	80,000 GAL			160,000 GAL			240,000 GAL		
% DIR	0	5	10	0	5	10	0	5	10
$150,000	1.02	1.58	2.56	1.96	3.05	4.94	2.84	4.42	7.15
I $175,000	.89	1.38	2.23	1.71	2.67	4.32	2.49	3.88	6.28
$200,000	.78	1.22	1.98	1.52	2.37	3.84	2.22	3.46	5.60

installation costs incurred by Seatrain was $150,000. As mentioned earlier, today's cost would be $206,716. If we assume economy-of-scale, then a value of $175,000 would be a reasonable estimate for installation cost (I). Horizontally we have three values of fuel consumption per cutter per year, with 160,000 gallons being the most likely value based upon current requirements. To use 80,000 gallons would require that the Coast Guard substantially relax their current running requirement. It is clear that over a twenty (20)-year period, the benefit/cost ratio exceeds one in every case except for the annual consumption of 80,000 gallons at a zero differential inflation rate.

Figure 3 illustrates the growth in benefit/cost ratio as project life is varied up to 20 years with a differential inflation rate of zero. For any given installation cost (I) and consumption value (C) the breakeven year may be determined at that point where the benefit/cost ratio exceeds 1.0. As can be seen breakeven was achieved for all combinations of I and C except in those cases of very low fuel consumption.

A more reasonable differential inflation rate (10%) is assumed in Figure 4. The benefit/cost ratios are much more favorable in this situation and breakeven is achieved in every case.

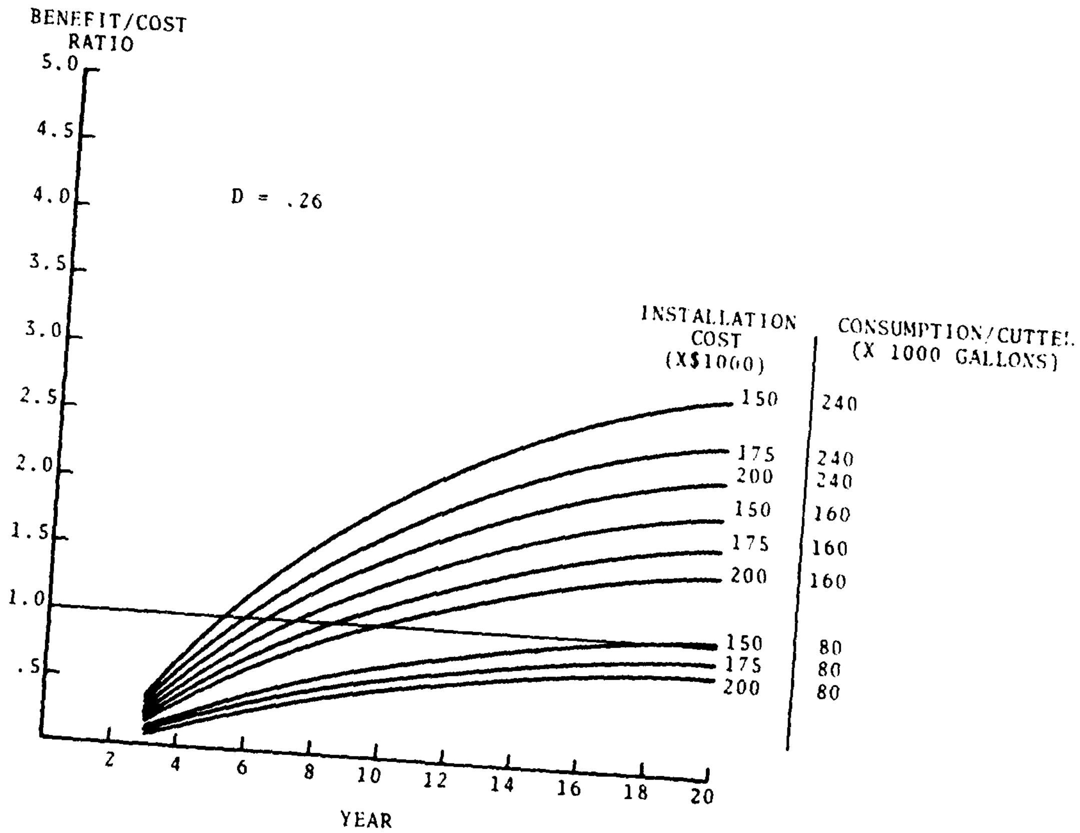

FIGURE 3. BENEFIT/COST RATIO FOR EMULSIONS IN GAS TURBINES (DIR = 0%)

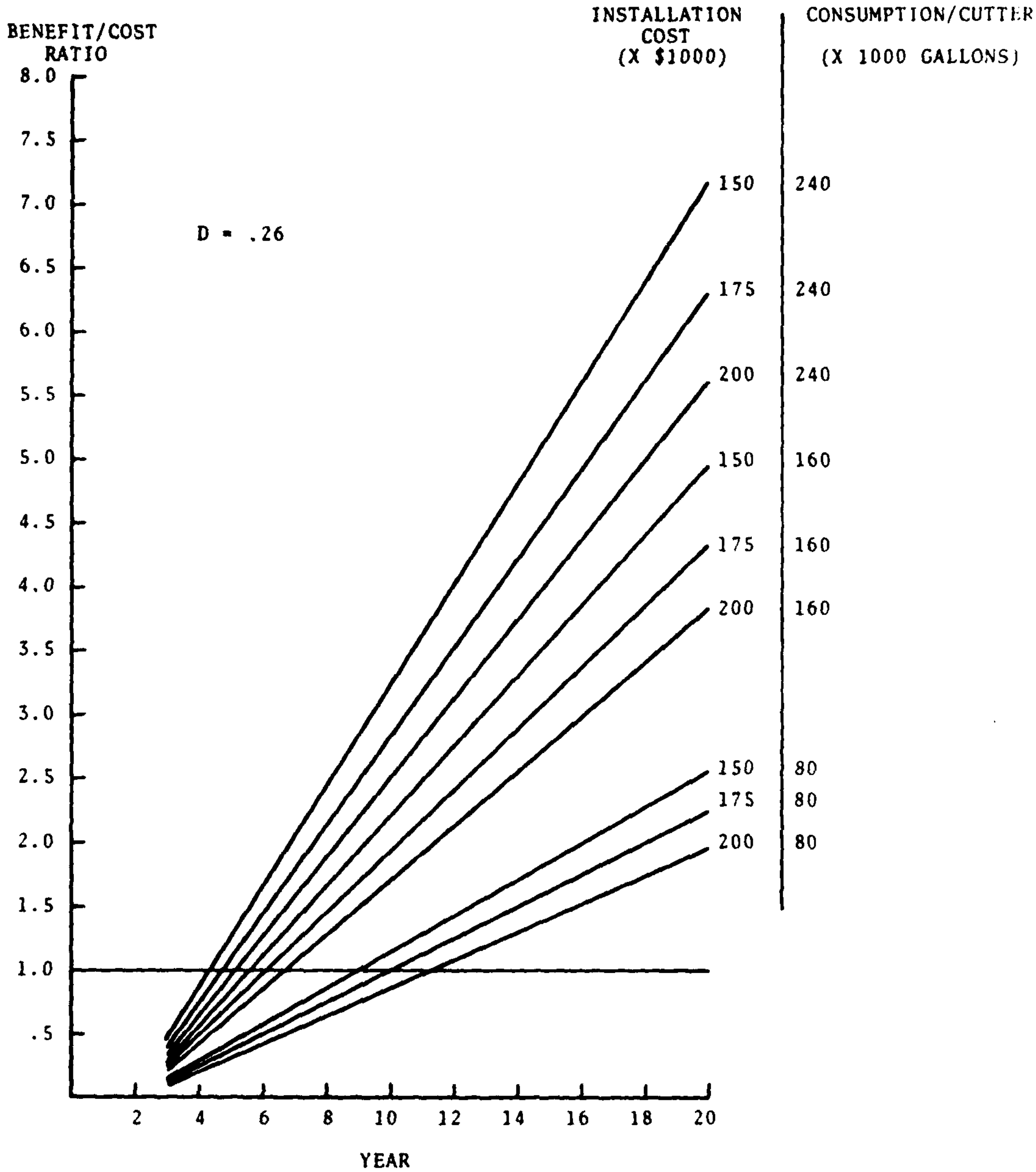

FIGURE 4. BENEFIT/COST RATIO FOR EMULSIONS IN GAS TURBINES (DIR = 10%)

4. POTENTIAL FOR USE OF BLENDED FUEL IN COAST GUARD DIESELS

4.1 GENERAL

Burning a blend of distillate and heavy fuel results in a reduction in energy costs by virtue of the lower cost for the heavy fuel. Blending 75% FS6 (viscosity = 3500 sec R1) with 25% marine diesel #2 results in a fuel with a viscosity of 600-650 sec R1. With proper preheating this heavier fuel can be tolerated by many medium speed diesel engines and while the feasibility for using such a fuel with the Fairbanks-Morse diesels on the "Hamilton Class" cutters has not been shown, for the purpose of the analysis performed here, this feasibility is presumed.

Much of what was discussed in Section 3 for emulsified fuels also applies to this discussion. The blend utilized in this discussion is the same blend used for the water-in-fuel emulsion discussed earlier. The only difference is that in the present case no water is added to form an emulsion.

4.2 COSTS AND BENEFITS

The differential fuel cost is the same ($0.26) as the previous example with gas turbines. The assumptions made for the cost/benefit analysis are reasonable although they are not based upon as firm empirical evidence as the gas turbine analysis. The assumptions are given in Table 7. The R&D cost to firmly establish feasibility and produce a prototype system on one of the cutters is presumed to be $500,000 and is applied at year zero. Installation of the first system then occurs as a result of the R&D effort. As a reasonable approach, three (3) more cutters are equipped in year 1, four (4) more in year 2, and four (4) more in year 3. Fuel consumption is 0.66×10^6 gallons per year per cutter, significantly higher than the gas turbine fuel consumption. The remainder of the assumptions are the same as those in the gas turbine case.

TABLE 7. ASSUMPTIONS FOR COST-BENEFIT ANALYSIS (DIESELS)

- o DISCOUNT RATE = 10%
- o INSTALLATION LIFE = 20 YEARS
- o INSTALLATION: 1 CUTTER YEAR 0 (RESULT OF R&D EFFORT)
  - 3 CUTTERS YEAR 1
  - 4 CUTTERS YEAR 2
  - 4 CUTTERS YEAR 3
- o R&D COSTS APPLIED AT YEAR ZERO = $500,000 (INCLUDES INSTALLATION COST OF FIRST CUTTER)
- o ANNUAL FUEL CONSUMPTION = $.66 \times 10^6$ GALLONS/CUTTER
- o SYSTEM MAINTENANCE AND OPERATING COSTS = $3.00/TON OF FUEL
- o DIFFERENTIAL FUEL COSTS = $.26/GAL

A summary of present value of costs over a period of twenty (20) years is shown in Table 8. The present value of benefits, is shown in Table 9. Arbitrarily bracketing fuel consumption with values of 0.4×10^6 gallons and 1.0×10^6 gallons and presuming installation costs similar to those used previously for gas turbines, the benefit/cost ratio tables of Table 10 may be constructed. It is clear from Table 10 that the benefit/cost ratio is very favorable over a project life of twenty (20) years at all values of installation costs and consumption.

Figure 5 shows the growth in benefit/cost ratio as project life is varied up to twenty (20) years. In this case, the differential inflation rate is zero. This situation is seen to be much more favorable than that shown in Figure 3 for gas turbines. In the present case, the benefit/cost ratio exceeds 1.0 at some point in the project life for all values of installation cost and consumption. In fact, breakeven is achieved before five (5) years in every case.

A more reasonable situation is shown in Figure 6 where the differential inflation rate is 10%. In this case, breakeven is achieved before four (4) years for every value of installation cost and consumption.

The reason for the dramatic increase in the benefit/cost ratio in the case of the diesels as compared to the gas turbines is the significantly higher annual fuel consumption of the diesels.

TABLE 8. PRESENT VALUE OF COSTS (DIESELS)

YEAR	COST	PVF	PV OF COSTS	PV OF CUMULATIVE COSTS
0	500K	1.0	500K	500K
1	3I	0.954	2.862 I	500K + 2.862 I
2	4 I + 0.0387 C	0.867	3.468 I + 0.0336 C	+ 6.330 I + 0.0336 C
3	4 I + 0.0774 C	0.788	3.152 I + 0.0610 C	+ 9.482 I + 0.0946 C
4	0.1161 C	0.717	0.0832 C	+ 0.1778 C
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.		.	.	.
20		0.156	0.0181 C	0.8288 C

FOR 20 YEARS: COST = \$500K + 9.482 I + .8288 C

WHERE: I = INSTALLATION COST

C = FUEL CONSUMPTION/CUTTER/YEAR (GALLONS)

TABLE 9. PRESENT VALUE OF BENEFITS (DIESELS)

		PVF			PV OF BENEFITS			PV OF CUMULATIVE BENEFITS		
		DIR				DIR			DIR	
YEAR	BENEFIT	0	5	10	0	5	0	0	5	10
0	0	1.0	1.0	1.0	0	0	0	0	0	0
1	1 CD	.954	.977	1.0	.954 CD	.977 CD	1 CD	.954 CD	.977 CD	1 CD
2	4 CD	.867	.933	1.0	3.468 CD	3.732 CD	4 CD	4.422 CD	4.709 CD	5 CD
3	8 CD	.788	.890	1.0	6.304 CD	7.120 CD	8 CD	10.726 CD	11.829 CD	13 CD
4	12 CD	.717	.850	1.0	8.604 CD	10.200 CD	12 CD	19.330 CD	22.029 CD	25 CD
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20		.156	.404	1.0	1.872 CD	4.848 CD		86.614 CD	134.440 CD	217 CD

FOR 20 YEARS: BENEFIT = 86.61 CD AT 0% DIR
= 134.44 CD AT 5% DIR
= 217 CD AT 10% DOR

WHERE: C = FUEL CONSUMPTION/CUTTER/YEAR (GALLONS)
D = DIFFERENTIAL FUEL COSTS

TABLE 10. BENEFIT/COST RATIOS (DIESELS)

	C/CUTTER/YEAR								
	$.4 \times 10^6$ GAL			$.66 \times 10^6$ GAL			1.0×10^6 GAL		
% DIR	0	5	10	0	5	10	0	5	10
\$150,000	4.00	6.20	10.01	6.02	9.34	15.08	8.19	12.71	20.51
\$175,000	3.62	5.61	9.06	5.49	8.52	13.76	7.54	11.70	18.88
\$200,000	3.30	5.13	8.27	5.05	7.84	12.65	6.98	10.84	17.49

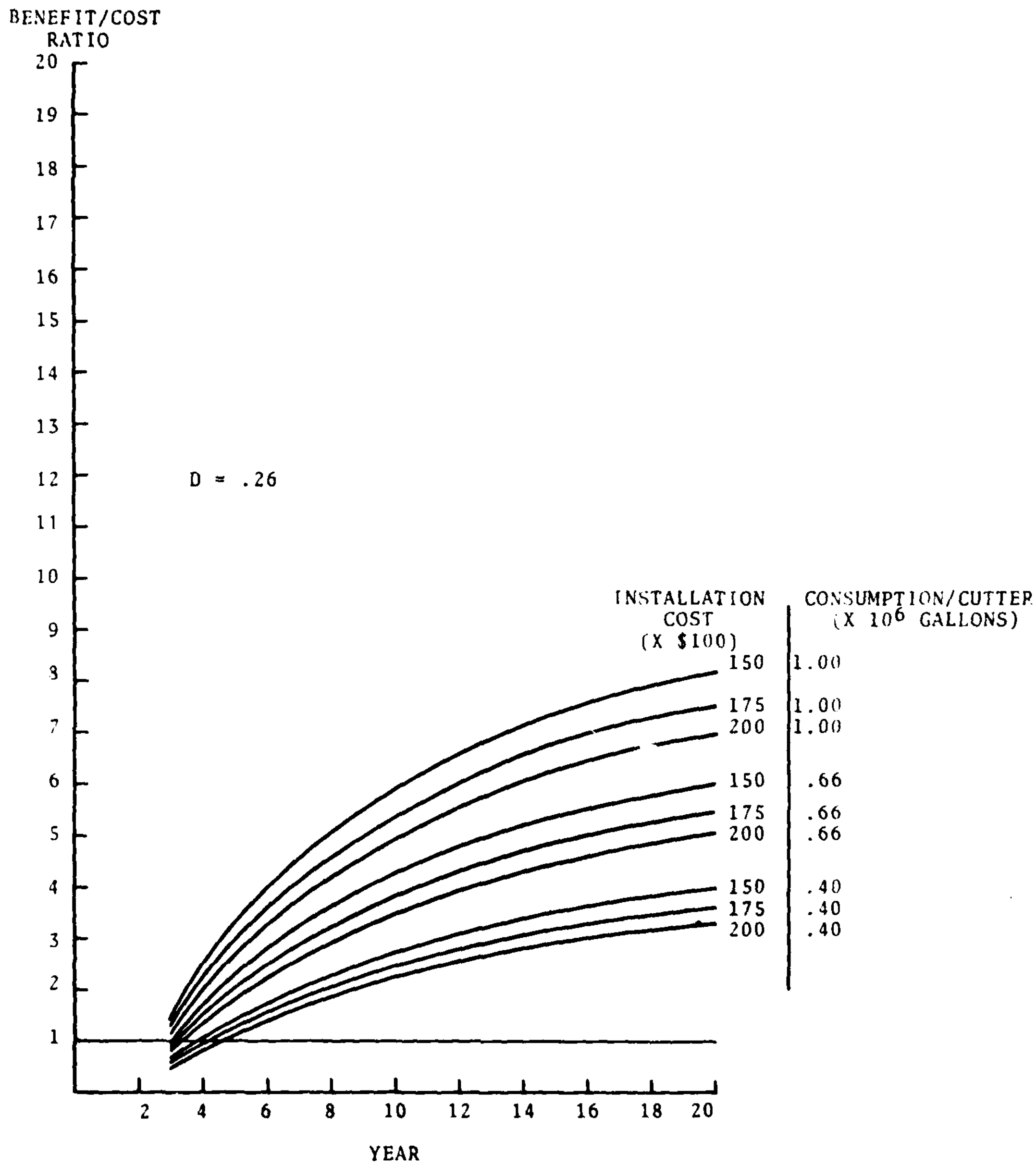

FIGURE 5. BENEFIT/COST RATIO FOR BLENDED FUEL IN DIESELS (DIR = 0%)

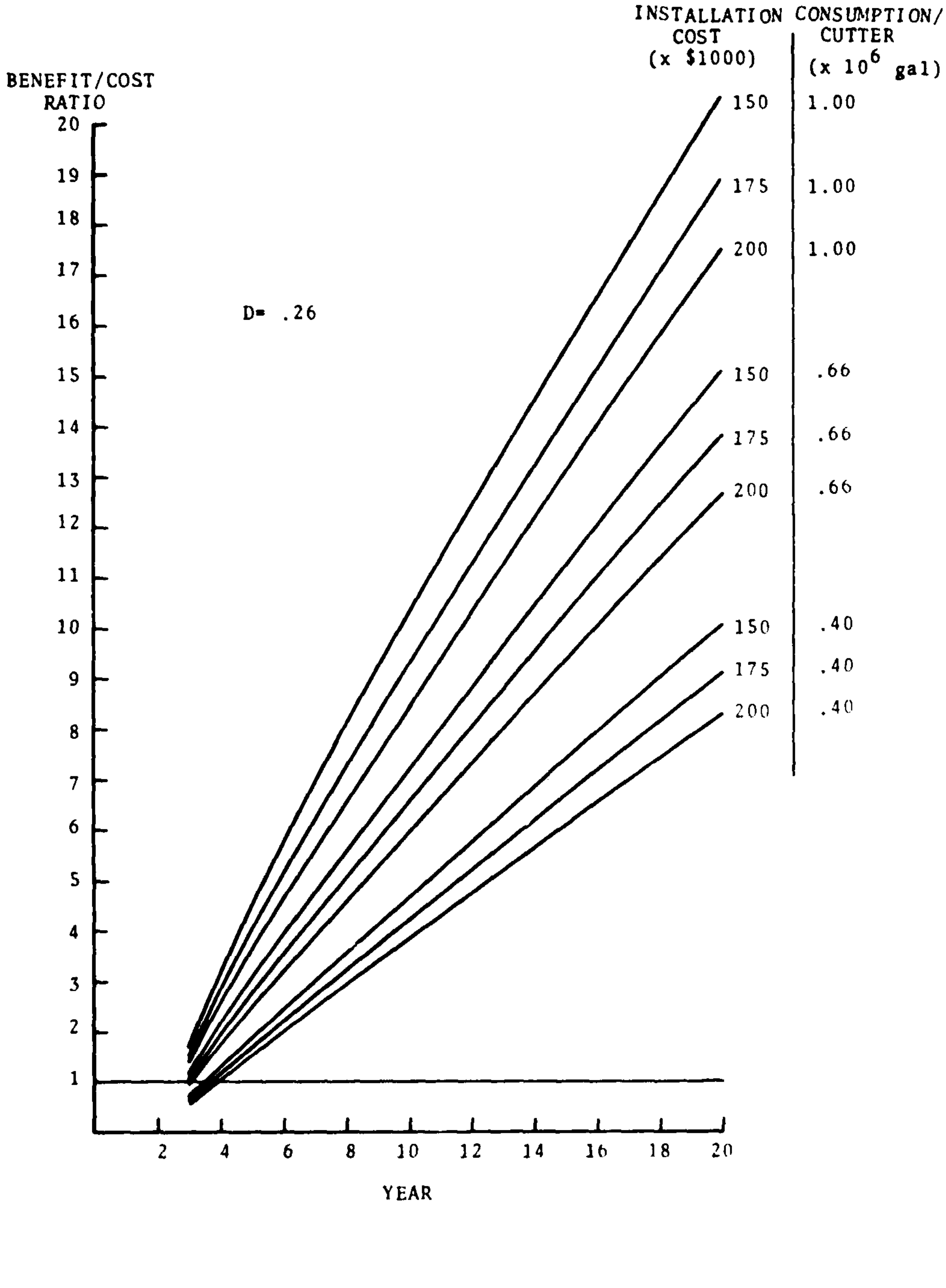

FIGURE 6. BENEFIT/COST RATIO FOR BLENDED FUEL IN DIESELS
(DIR = 10%)

5. CONCLUSIONS AND RECOMMENDATIONS

In summary, the use of blended fuel emulsions in gas turbines and blended fuel in diesels appears to be technically feasible and economically very attractive as oil prices continue to rise and the world wide availability of lighter, more refined fuels becomes more uncertain. From the information gathered and analysis performed in this current effort, the following specific conclusions may be drawn and recommendations made.

5.1 CONCLUSIONS

- Use of blended fuel emulsions in a Pratt and Whitney FT4 gas turbine is technically feasible based upon the experience of Seatrain Lines.
- Design of the fuel handling system for blended fuel emulsions is essentially complete, requiring very little additional R&D.
- At current fuel prices and consumption rates of the "Hamilton Class" cutters, use of blended fuel emulsions in the gas turbines would result in considerable fuel cost savings over the life of the cutter.
- Benefit/cost ratios for the use of blended fuel emulsions in gas turbines exceeds 1.0 for all rates of consumption analyzed if the differential inflation rate (DIR) is 10%, and is less than 1.0 only when consumption is very low and the DIR is 0%.
- Additional R&D is necessary to assure technical feasiblilty of burning blended fuels in diesels currently installed in "Hamilton Class" cutters.
- Presuming technical feasiblity, use of a blended fuel in the diesels on the "Hamilton Class" cutters is more favorable economically than the use of emulsions in the gas turbines due primarily to the higher annual fuel consumption of the diesels.

5.2 RECOMMENDATIONS

- Further R&D should be performed on blended fuel for the "Hamilton Class" cutter diesels to assure the technical feasibility of this fuel cost reduction technique.
- The use of blended fuel emulsions in the gas turbines of the "Hamilton Class" cutters should be given serious consideration if further R&D shows that the use of blended fuel in the diesels is feasible. Both propulsion systems used on these cutters could then burn the same blend, simplifying the design and operation of the fuel handling system.

REFERENCES

1. Kasel, E.A., Newton, C.L., and Walter, R.A., "Engine Performance Improvement for the 378-foot High Performance Cutter," U.S. Department of Transportation, United States Coast Guard, Report No. CG-D-11-78, June, 1978.

2. "Commissioning the MaK 8M601 Engine," Shipbuilding & Marine Engineering International, November, 1979.

3. "Sulzer AS 25/30 Engines to Burn Heavy Fuel," Shipbuilding & Marine Engineering International, November, 1979.

4. Storment, J.O. and Coon, C.W., "Single Cylinder Diesel Engine Tests with Unstabilized Water-In-Fuel Emulsions," Southwest Research Institute, Report No. CG-D-13-78, August 1978.

5. Coon, C.W., "Multi-Cylinder Diesel Engine Tests with Unstabilized Water-In-Fuel Emulsions," Southwest Research Institute, Report No. CG-D-27-80, March, 1981.

6. Murayama, T., Morishima, Y., Tsukahara, M., and Minyjamoto, N., "Experimental Reduction of NO_x, Smoke and BSFC in a Diesel Engine Using Uniquely Produced Water (0-8%) to Fuel Emulsion," Society of Automotive Engineers, Inc., Paper No. 780224, Detroit, Mich., February 22 - March 3, 1978.

7. Cornet, I., and Nero, W.E., "Emulsified Fuels in Compression Ignition Engines," Industrial and Engineering Chemistry, October, 1955.

8. Ivanov, V.M., and Nefedow, P.I., "Experimental Investigation of the Combustion Process of Natural and Emulsified Liquid Fuels", NASA Technical Translation, NASA TTF-258, January, 1965.

9. Dryer, F.L., "Fundamental Concepts on the Use of Emulsions as Fuels," Guggenheim Laboratories, Princeton University, Aerospace and Mechanical Sciences Report No. 1224, April, 1975.

10. Spadaccini, L.J., Pelmas, R., "Evaluation of Oil/Water Emulsions for Application in Gas Turbine Engines," Symposium

REFERENCES (CONT.)

on Evaporation-Combustion of Fuel Droplets-Presented Before the Division of Petroleum Chemistry Inc., American Chemical Society, San Francisco Meeting, August 29-Sept. 3, 1976.

11. Law, C.K., "A Simplified Model for the Combustion of Fuel/Water Emulsion Droplets," Fall Meeting of the Eastern States Section of the Combustion Institute, Philadelphia, PA.

12. Birchley, J.C., and Riley, N., "Transient Evaporation and Combustion of a Composite Water-Oil Droplet," Combustion and Flame 29, 145-165, 1977.

13. Moses, C.A., "Laboratory Combustor Tests on Fuel Emulsions for the Reduction of Exhaust Smoke from Jet Engines," presented at the Symposium on the Use of Water-in-Fuel Emulsions in Combustion Processes, U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA, April, 1977.

14. Klarman, A.F., Rollo, A.J. and Scott, H.C., "Evaluation of Water/Fuel Emulsion Concept for Test Cell Smoke Abatement," Naval Air Propulsion Center, Trenton, NJ, Report No. NAPC-PE-7, March, 1978.

15. Shayeson, M., General Electric Company, Personal Communication with the Author.

16. Nealis, C.R., and D.A., O'Neil, "Blended Residual Fuel Testing Abroad the Gas Turbine Powered Vessel Asialiner," Paper presented to the Society of Marine Port Engineers of New York, N.Y., Inc., January 19, 1977.

17. "Seatrain FT4 Fleet to Burn Blended Bunker C," Gas Turbine World, March, 1977.

18. Novak, S.M., Oirschot, Piet W.C.M., Young, H.P. and O'Neil, D.A., "Increased Profits for Gas Turbine Containerships by Unique Applications of Combustion Technology and Hydrodynamics," Proceedings of the Annual Meeting of the Society of Naval Architects and Marine Engineers, November, 1977.

REFERENCES (CONT.)

19. Macintyre, N.L., "Considerations for Improving the Fuel Economy of Gas Turbine Propulsion Plant Designs," Presented to the Southern New England Section of the American Society of Naval Engineers, December 1, 1977.

20. O'Neil, D.A., "Marine Gas Turbine Engine Systems - Viable Propulsion Plants for Certain Shipboard Applications," for the Society of Naval Architects and Marine Engineers, San Diego Section, Sept., 15, 1971.

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